NEW VALUES IN LAMINATE DESIGN AND MANUFACTURING
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1 Background in Laminate Design
Laminate design evolution through the years has been restricted to 4 ply angles of 0, ±45, 90, with mid-plane symmetry, balanced off-axis angle in ±45, and a trend to use thick plies to reduce the layup time. A recent invention of bi-angle thin-ply non crimp fabric (NCF), with a trade-name C-Ply, offers values in laminate design and manufacturing beyond these traditional restrictions. Significant weight and cost savings can be achieved from having stronger and delamination resistant laminates.

2 C-Ply Fabric and Tape
Chomarat, a French fabric supplier for over 100 years, has developed a new class of NCF that has 2 ply angles of high-quality thin plies (from 25 to 100 gsm) with non-invasive stitching delivering custom-engineered laminates with unusual values for performance and cost. With epoxy prepreg, C-Ply with T700 fiber cured in vacuum bagging was found competitive with T800/epoxy cured by autoclave. A conservative, practical first-ply-failure (FPF) criterion is recommended where micro cracking is not permitted. Chomarat machine is also capable of making a range of shallow angles such as [0/22.5], [0/30], and so on.

3 Increased CAI and Delamination Resistance
With bi-angle C-Ply with shallow angles as the building block instead of the traditional all [0] fabric or prepreg, laminates with many angles can be made; e.g., [π/8] can be made with [0/22.5] tape with 4 layup axes, and [π/6] with [0/30] using 3 layup axes. Significant increased compression after impact (CAI) was found.

In addition, the angle difference between adjacent plies is at 22.5 degrees for [π/8] laminates, and 30 degrees for [π/6]. These smaller angles than the traditional [π/4] family that has 45 and 90 degrees in angle difference should make the C-Ply laminate more resistance to delamination. In addition to many diversely spread fibers to disperse impact energy, thinner plies are intrinsically resistance to delamination as exhibited in the increased CAI above and examples of suppressed edge delamination found in literature.

4 Homogenized Laminate
Thin plies are more than anti delamination, they can make laminates more easily homogenized. When a laminate is stacked with the same, repeated sub-laminates, it is homogenized when the number of sub-laminates reach 16 (within a few percentage points for C-Ply). There are two significant values from having homogenized laminates: 1) the
traditional mid-plane symmetry can be ignored. A nonstop stacking is faster and less prone to error; 2) laminate profile by optimization is possible. Weight savings of 50 percent over aluminum is easily achieved. More importantly, stacking sequence can now be ignored. Stacking sequence is not optimized because of its huge permutations; e.g., see those calculated by Jeremy Sanford of Spirit.

5 Automated Tape Laying

A combination of bi-angle and thin plies offered by C-Ply can have a direct impact on recurring cost of manufacturing. The traditional 4-axis layup of the 4-ply-angle laminate can be hastened by a factor of 2.7 when C-Ply tape with 2 axis layup is used. Such prediction and validation were found by Jim Hecht of MAG.

6 Scissoring Tape

C-Ply can also offer a family of angle-ply tapes such as [-22.5]. Depending on the fiber and matrix, the angle-ply tape can have Poisson ratio larger than unity. Its scissoring capabilities can make the tape pliable to complex curvatures. When laid up with helical angles, a circular cylinder with heads may be wound without wrinkle.

7 Spiral Stacking

For C-Ply with two angles it offers special values for complex laminates like [π/6], [π/8] and beyond with spiral stacking. The resulting laminates are high in CAI and delamination resistant. For fuselage skin, spiral stacking may offer a good solution with thin plies so a minimum gage can be designed and manufactured with desired CAI.

8 Conclusions

C-Ply offers design and manufacturing of composites structures many opportunities. Through engineering, unique laminates can be explored. The starting material can be carbon, glass and their hybrids. The resin system can be thermoset or thermoplastic. Ply thicknesses can be thick and thin to adjust to the need of structures. C-Ply is not limited to 2 angles; e.g., a patent-pending herringbone tape can have 3 angles. For this case, 1-axis layup can be practical. Then the reduction in recurring cost can be by one order of magnitude. Curing can be by vacuum bag or autoclave.